NATIONAL PUBLIC RADIO

Report to the Corporation for Public Broadcasting

Digital Radio Coverage & Interference Analysis (DRCIA) Research Project

Final Report

Deliverable 6.2.2

CPB Account No. 10446

Reporting Date: May 19, 2008

Digital Radio Coverage & Interference Analysis (DRCIA) Research Project

Conducted by NPR Labs in partnership with, and support from,
the Corporation for Public Broadcasting

DRCIA Final Report

npr labs

National Public Radio
635 Massachusetts Avenue NW
Washington, DC 20001
www.nprlabs.org

TABLE OF CONTENTS

npr labs

Digital Radio Coverage & Interference Analysis (DRCIA) Research Project

Final Report on CPB Contract No. 10446

Executive Summary

NPR, through the Corporation for Public Broadcasting (CPB) - funded Digital Radio Coverage and Interference Analysis (DRCIA) project, examined the coverage capabilities and impact of in-band on-channel digital audio broadcasting (IBOC DAB) in the United States. IBOC DAB holds great potential for public radio as these stations enter into a digital transmission era. As of this report's date, some 380 public radio stations are broadcasting in digital, providing over 500 digital program streams from over 130 multicasters, of whom over three dozen are triple-casting.

Since this digital transmission system may be added to existing broadcast stations in the FM band (and AM as well), CPB created the DRCIA project for three primary goals: to determine the coverage capabilities of (1) legacy analog FM service and (2) IBOC DAB service, and (3) evaluate the impact of the digital transmission system on reception of analog FM service, assuming all stations are operating in hybrid mode. CPB commissioned NPR Labs (which enlisted experts from other organizations on a subcontract basis) to conduct an extensive study of these issues. This study was recommended by the Digital Consultancy in 2005, was carefully designed by CPB and NPR to answer these questions, and was launched in late 2006.

As described in the full report, available at www.nprlabs.org, NPR Labs, led by project director and Senior Technologist John Kean, performed detailed receiver performance testing that was validated by carefully selected field tests. The analog receiver performance data was used to develop maps predicting, for the first time, actual coverage available to public radio listeners. Drawing on tests of digital receivers, NPR Labs spent a year painstakingly developing the first field-corroborated coverage prediction algorithm for IBOC DAB. This yielded more firsts: maps of public radio station coverage assuming all stations are operating in hybrid mode, for both their digital and analog services.

As summarized below, all 850 public radio stations were mapped for three types of reception with analog and digital service using a total of five interference-limited coverage scenarios:

<table>
<tr><th></th><th colspan="3">Analog Coverage Maps</th><th colspan="3">Digital Coverage Maps</th></tr>
<tr><td rowspan="2">Studies of 850 public radio stations</td><td>Mobile</td><td>Indoor</td><td>Portable</td><td>Mobile</td><td>Indoor</td><td>Portable</td></tr>
<tr><td colspan="3">Analog-only</td><td colspan="3">IBOC DAB at 1% power</td></tr>
<tr><td rowspan="4">Detailed studies of 75 sample stations</td><td>Mobile</td><td>Indoor</td><td>Portable</td><td>Mobile</td><td>Indoor</td><td>Portable</td></tr>
<tr><td colspan="3">Analog-only</td><td colspan="3">IBOC DAB at 1% power</td></tr>
<tr><td colspan="3">Analog with 1% IBOC on all stations</td><td colspan="3" rowspan="2">IBOC DAB at 10% power</td></tr>
<tr><td colspan="3">Analog with 10% IBOC on all stations</td></tr>
</table>

It is notable that the coverage maps for this study are not based on standardized values, like most coverage maps. The DRCIA maps have been created from actual receiver-derived measurements of stereo sensitivity and interference susceptibility, combined with practical receiving antenna efficiencies, building attenuation loss estimates and other factors to determine coverage. A calibrated point-to-point pathloss model was used to create terrain-sensitive coverage predictions. To represent typical vehicular, residential and portable reception, field strengths were determined at a receiving height of 1.5 meters (5 feet) above ground.

A set of 75 stations were selected to evaluate the key study goals. Two-thirds of these stations were selected from the 50 largest radio markets to represent the majority of the public radio system, while 25 additional stations were selected from smaller markets that provide substantial service to an outlying population. The set was analyzed in detail and population was counted for listener and economic evaluations.

The following summarizes key technical results of this study:

- With 1% IBOC transmission power operating on all stations:
  - Mobile IBOC DAB coverage would be 85% of quality analog coverage, by population, for the 50 sample stations.
  - Mobile analog FM population would be reduced an average of 14% for the sample stations due to interference from IBOC DAB. This affects most stations in varying degrees in outlying portions of their mobile analog service area.
- With 1% IBOC transmission power:
  - Indoor IBOC DAB service covers approximately 38% of the population served by analog with a large (83%) standard deviation. Results for portables are similar.
  - Analog FM indoor covered population would be reduced by IBOC interference an average of 6% for the sample stations. Interference to portable analog service is minimal. These relatively small impacts are due the higher field strengths required to receive the digital signal.
- With 10% IBOC transmission power:
  - Mobile IBOC DAB coverage would average 117% of quality analog coverage, by population, for all 50 sample stations.
  - Mobile analog FM covered population would be reduced an average of 26% for the sample stations. Interference would affect some stations severely in portions of their analog mobile service area: 41% could lose one-third or more of their covered population and 18% would lose more than half of their population.
- With 10% IBOC transmission power:
  - Indoor and portable IBOC DAB covered population totals would be 83% and 81% of analog coverage, respectively.
  - Analog FM indoor and portable covered population totals are reduced by 22% and 6%, respectively. Interference would affect some stations severely in portions of their analog indoor service area: 27% could lose one-third or more of their covered population and 16% could lose more than half of their population. Due to higher required field strengths to overcome low receive antenna efficiencies, indoor portable

reception is relatively slight: only 6% of stations are predicted to receive analog portable interference exceeding one-third of their analog-only covered population.

NPR Labs' general conclusions of the study results are:

- At the current 1% IBOC power, mobile digital coverage only slightly underperforms quality analog coverage, while indoor and portable digital coverage is substantially smaller than analog for most stations.
- Station impacts from IBOC DAB to analog FM vary widely from station to station, primarily due to the fact that the IBOC DAB digital sidebands are actually co-channel to neighboring stations on first-adjacent channels; the FCC's first-adjacent allocation rules for analog FM cannot adequately protect against some close-spaced conditions.
- Current field evidence, including listener reports, of interference to analog reception from IBOC DAB at 1% power is minimal. This may suggest that interference is less noticeable than predicted, however, due to the noiselike nature of IBOC-to-analog interference, which lacks the audible clues of typical analog-to-analog interference, it may be difficult for field listeners to identify an interfering IBOC signal and report their impaired reception.
- Improvements in IBOC DAB receivers and antennas are not currently expected to be a significant remedy for the shortfall in indoor and portable reception. Other techniques, likely transmission-based, will be needed to improve service.
- At 10% IBOC transmission power, most stations would gain covered population, approximately equaling analog indoor and portable and exceeding mobile.
- Unqualified 10% IBOC transmission power is predicted to cause substantial interference to analog reception of a significant number of first- and second-adjacent channel stations.
- Stations on "non-commercial" channels (88.1-91.9 MHz) and "commercial" FM channels (92.1-107.9 MHz) would receive similar amounts of interference to their analog operations from IBOC DAB at 10% power. This is notable since it was expected that commercial channels have more conservative protection standards.
- Initial projected system-wide estimates of the costs of deploying a combination of optimization strategies for indoor digital coverage parity could approach a doubling of transmission investments.
- Input interference to existing analog FM translators, should all stations convert to IBOC DAB, is expected to affect approximately 5% of all translators.

Our findings indicate that several potential strategies should be investigated, and where practical, developed for system-wide improvement in digital radio service:

- Single Frequency Network (SFN) boosters may be approaching Independent Demonstration Of Viability maturity, providing a potentially critical strategy to improve digital indoor coverage, where needed, while controlling analog interference effects. In addition to technical development and testing, an economic analysis is indicated.
- Limited elevation of IBOC transmission power, including separate directional antenna systems for the IBOC transmission and asymmetrical sideband power, should be developed and tested to limit interference to neighboring FM stations.

- Further testing on the impact of elevated IBOC power on consumer receivers, including radio reading service SCA receivers, is needed to develop rational policies for sideband power increases, where appropriate [not all stations will consider it necessary or appropriate].

NPR Labs has worked closely with CPB staff throughout this intensive project and we are gratified by their active engagement, counsel and commitment to this project. The advanced research methods and analysis used in this study are unprecedented. The underlying data developed is voluminous and far reaching. System-wide strategies will require coordination in concert with the project's Communications Plan, as well as focused follow-up research validating and refining promising optimization approaches.

Acknowledgements

NPR expresses our gratitude to the staff of CPB's Digital Media Technologies unit – especially Don Lockett, Senior Director of the unit, Brian Gibbons and Doug Vernier, who individually invested untold hours actively engaged in the progress and rigor of this study from inception to completion.

This study could not have happened with the extraordinary insights and dedication of NPR's Senior Technologist John Kean, the project manager on this effort. Kyle Evans, Jan Andrews, Ellyn Sheffield, Mike Starling, Dianne Brace, Daniel Schwab, and Barbara Freeman also contributed extensively throughout the study.

NPR Labs additionally thanks the staff at ITS in Boulder for customization of the CSPT planning tool for automating the execution of the mapping and population counts. Former NPR staffer Matthew Burrough also contributed to this project. Special thanks also goes to the staff of NPR's Audience Insight and Member Services groups for invaluable work on the signal sensitivity studies, especially Lori Kaplan, Barbara Appleby, Matt Gallivan, and Ben Robins.

Communicate with us, view our complete DRCIA report, and track ongoing digital radio coverage work at: www.nprlabs.org/Research/DRCIA.php.

n p r labs

National Public Radio
635 Massachusetts Avenue NW
Washington, DC 20001
www.nprlabs.org

2 Introduction

The CPB/NPR Digital Radio Coverage and Interference Analysis Project grew out of discussions surfacing during the 2005 CPB Radio Digital Consultancy. It might have been equally well identified as "HD Radio Optimization Study on Limiting Disenfranchisement to Analog Listeners and Improving Service to HD Radio Listeners."

At that time, only 115 public radio stations were on the air with digital broadcasting, and only 15 were multicasting. HD Radio was still a relatively new development, and concerns over the interference potential to and from IBOC signals were the focus of attention among broadcasters and trade press. At this writing, in March, 2008, there are more than 350 public radio stations operating in HD Radio, with over a third of those multicasting.

As with most technology introductions, skeptics initially declared HD Radio as fatally flawed due to substandard codec performance, use of a proprietary standard, lack of a regulatory mandate, lack of multi-channel capacity, etc. Later deterrents pointed to the lack of affordable receivers, lack of support from automakers, and absence of subsidies to stimulate manufacturing.

One early report had surfaced from a community station that had reported loss of a pocket of listeners in a community near Sacramento, when North Highlands station KQEI commenced IBOC operations on 89.3 MHz. In the intervening period of time, only two additional reports of interference have been received – including another one from a station in Northern Minnesota experiencing loss to regular reception, this time due to activation of a second adjacent channel IBOC operation. Here again, the pocket of reported interference was beyond the protected contour of the desired station. In this instance, it was determined that this interference was spectral regrowth energy, and as it presented a second adjacent channel scenario it was recommended that the added energy should be treated with a transmission filter.

Although the reports of second adjacent interference appeared to be associated with a single manufacturer, the energy was shown to be under the FCC mask and thus not subject to enforcement action. This scenario had been observed in several other areas, mostly in the commercial band, but with additional filtering the second adjacent energy was greatly minimized and the interference essentially eliminated. CPB identified this problem early on and established a special program for making needed filters available.

In the final instance of reported interference from IBOC operation, one radio reading service in Kentucky reported hiss being heard in one make of SCA receiver operating on 67 kHz. This model of receiver is one unknown to NPR Labs, and was not among the makes and models noted by the IAAIS as a model in the field when we originally tested SCA receiver susceptibility to IBOC transmissions in 2002.

The solutions to each of these three scenarios are similar to solutions that have been required in the analog world for various types of RF interference:

- In the case of the early report of lost analog listening – well beyond the protected contour of the affected station – this instance represents an ideal location for placing a translator to restore service. This is the same solution that has been required in many similar instances where listening beyond protected contours was affected by establishment of new transmitters. Translators are the ideal solution and basis for extending service to nearby communities where pockets of public radio listeners would be without service otherwise.

- In the case of the second adjacent interference problem, filtering out-of-band emissions on the offending IBOC transmitter is the recommended solution and CPB has wisely established a fund to deal with these rare instances.
- Finally, in the case where a particular model of receiver is affected by susceptibility to host compatibility issues, the only solution – as was often a last resort in TV-6 interference cases – is replacement of the substandard, inferior receivers with models that typically reveal no adverse consequences in the presence of IBOC transmissions.

In short, with only three reports of interference making it to NPR Labs within the timeframe of this study, we believe that IBOC interference to existing analog FM transmissions to date has been minor, and most often associated with the vulnerable instances of residual listening beyond protected contours (where desired signal strength is beyond distances at which the FCC would expect reliable reception to occur). Reports of IBOC interference have been far fewer, for example, than the many analog reports of interference from FM modulators and pirate transmissions. However, it should be noted that these forms of interference are far easier to identify than IBOC interference to analog reception, which is manifested as increased noise with no identifiable source. Nevertheless, should the level of interference to analog listeners rise to a noticeable level on any widespread basis we believe reports would have occurred.

At the same time, this study does document significant under-service of digital versus analog coverage. On the one hand, the extremely low 1/100th power IBOC transmissions are remarkably good – but the disparity in analog versus digital coverage is posing a problematic dilemma for stations that have invested heavily in original content for their new multicast HD Radio offerings.

For example, in reasonably flat terrain, with high power, at good elevation, there are a number of stations with good coverage over their core analog listeners. Markets such as Tampa, New Orleans, Chicago, and Washington, D.C. are reporting reasonably good matches between protected analog and new digital listening. However, even in these reasonably well performing HD Radio markets, actual analog listening always exceeds the coverage available with HD Radio. In response to this reality, a group of commercial broadcasters began exploring the compatibility issues associated with raising IBOC carrier power by a uniform 10 dB.

The results of those field studies have been recently made available to NPR Labs and they point to obvious increases in digital coverage, with purportedly minimal instances of objectionable interference to either the host station or the most susceptible adjacent channel stations. It should be noted, however, that the tested stations are not fine-arts formats that might reveal more impairments and that the talk programming did register more impairment than the music programming.

The rules for signal contour overlap protection in the NCE-FM Reserved Band differ from the mileage-based separations of the commercial, Non-Reserved Band channels. This lack of a “mileage buffer” based on maximum facilities with the station classes would seem to present a different impact to typical public radio listeners, especially with a higher density of stations at minimal contour protection. However, as discussed further in Section 3.1.3, there appears to be little difference in the potential impact on IBOC on analog service between the Reserved and Non-Reserved Bands. This could be due to a more efficient channel "packing" model used by the FCC to allocate channels to communities than the random selection of channels and communities used by Reserved Band applicants.

Notwithstanding the similarity in predicted interference potential of IBOC to analog channels, the high incidence of news and talk programming on public radio lacks the density of modulation achieved by aggressively processed music stations, which can better mask interference. (Even on popular music based formats, public radio generally processes the audio for higher fidelity, resulting in lower density of masking energy in the resulting modulated waveform.) The higher potential sensitivity, related to both the nature of the content, and the caliber of the audio processing and random tight spacings, reinforces the need for public radio to be guarded about a wholesale 10 dB power increase in IBOC carrier levels.

3 Coverage Assessments

This report discusses NPR's overall approach to the DRCIA project and presents the calculated results of key studies. Interpretations and projections of the findings are included. The selections of stations for study of digital coverage and potential analog impact is discussed in Section 3, followed by a discussion of the coverage and interference prediction methodologies for both analog FM and IBOC DAB in Sections 3.1.1 through 3.1.7.

The development of the IBOC DAB coverage prediction model is discussed in Section 3.2. This section includes the development of improved measurement instrumentation for signal measurement and drive-test measurements of 10 specially-selected stations to validate the model.

This report also includes new research material that is helpful to the impact analysis of IBOC DAB, such as the relationship between public radio listening and received signal strength in Section 3.1.4. The potential for increased interference to existing FM translators from IBOC DAB transmission is discussed in Section 3.1.6 and the results of receiver-induced third-order intermodulation effects are presented in Section 4.1.2.

Coverage maps were prepared for all CPB-qualified public radio FM stations in the U.S., numbering approximately 850 as of January, 2007. The map studies covered the following service types:

- Analog-only mobile (vehicular) service
- Analog-only indoor service
- Analog-only portable service
- IBOC DAB at 1% mobile service
- IBOC DAB at 1% indoor service
- IBOC DAB at 1% portable service

In addition to the above map studies, stations in the 50 largest radio markets and 25 specially-selected small markets included the following additional studies:

- Analog mobile service with 1% IBOC DAB interference
- Analog indoor service with 1% IBOC DAB interference
- Analog portable service with 1% IBOC DAB interference
- Analog mobile service with 10% IBOC DAB interference
- Analog indoor service with 10% IBOC DAB interference
- Analog portable service with 10% IBOC DAB interference
- IBOC DAB at 10% mobile service
- IBOC DAB at 10% indoor service
- IBOC DAB at 10% portable service

The map studies for the 50 large and 25 small markets included population counts, based on the 2000 U.S. Census. This population data was used in the coverage and economic impact studies discussed later herein. The maps were rendered as JPEG image files and provided to CPB on CD-ROM disks.

3.1 Coverage Prediction Methodology

NPR Labs selected the Communication System Planning Tools (CSPT), developed by the Institute for Telecommunication Sciences (ITS), after an extensive search and evaluation process.[1] Also known as *RF-Analyst* in the military community, the tool combines a powerful general-purpose GIS system with existing and planned electromagnetic wave prediction models. The CSPT extensions to ArcGIS® were developed for NPR Labs to IBOC DAB system analysis and multi-station planning.

CSPT is a menu-driven and icon-driven RF design tool for frequencies from 20 MHz to 20 GHz. CSPT allows the user to connect to a variety of image catalogs and terrain libraries which cover most of the world. The user can create specific analysis areas using these catalogs and libraries and can then perform propagation scenarios for his/her application. These applications can range from outdoor coverage studies of large scale areas of hundreds of square miles to indoor propagation studies of one building in an urban environment.

The following sections describe the derivation of coverage and interference values used in the map studies and the tools used to generate the maps.

The DRCIA maps used terrain-sensitive point-to-point pathloss predictions, instead of the long-standing FCC contour-line method. This provides high geographic resolution of coverage, as well as higher prediction accuracy.

Unlike traditional maps that are based on nominal field strengths, such as the F(50,50) 60 dBu contour, we based our maps on a set of signal link budgets for each service type that represent a realistic prediction of coverage, based on factors such as receiver performance, receive antenna efficiency, building penetration loss, and signal availability under fading conditions.

While traditional maps are facility-based, that is, depict coverage based only on the signal radiated by the target station, all of the DRCIA map coverage is interference-limited. This required the development of interference models and ratios that were derived from measurements of 50 analog and digital consumer receivers.

3.1.1 Analog Assumptions

The coverage studies began with the selection of CPB-qualified stations used in the later studies of coverage and interference.[2] This required the selection of stations in 50 of the largest radio markets and 25 smaller radio markets. There are 299 radio markets defined by Arbitron, Inc. to demarcate the geographic areas and populations in this study.

---

[1] The Institute for Telecommunication Sciences (ITS), located in Boulder, Colorado is the research and engineering arm of the National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce. ITS receives direct support from the Department of Commerce, other government agencies and U.S. industry. ITS performs telecommunications research and provides technical engineering support on a reimbursable basis. ITS also has cooperative research agreements with private companies.

[2] The details of these selections are described in the “DRCIA Market Selection Report” dated December 31, 2006, and the “DRCIA Interim Report” dated January 31, 2007, which are appended to this report.

The number of CPB-qualified stations in the 50 largest markets totaled 256 at the time of this study, with a few markets containing a dozen or more public radio stations. To provide a statistically representative sample we examined the distribution of all 256 stations by FCC Class (facility size, from Class A to Class C). From this distribution we selected 50 stations, one per market, which represented the same distribution per market as in the overall population. This sample population is used in the large-market studies discussed later in this report. The sizes of the 50 markets span a wide range of total population for each, ranging from New York and Los Angeles on the largest to Hartford, Connecticut and Providence Rhode Island on the smallest.

A purpose of "twenty-five smaller markets" was to address the conditions for stations with peripheral audience coverage, such as cases where communities of significant size lie just outside the reliable IBOC DAB coverage, but within the usable coverage of the analog FM host. We anticipated that stations with a substantial audience located geographically at the periphery of analog FM coverage would be more affected by and IBOC DAB coverage shortfall than stations that serve dispersed suburbs or rural areas in the outlying coverage area. As a result, they may have a greater need for service expansion techniques to fill in missing IBOC DAB coverage in those audience concentrations.

To prepare this list we examined the FCC contour coverage of all stations in markets ranked 51 through 299, and selected stations that show towns or cities of significant size in the area between the 50 dBu and 66 dBu contours. Since these stations represent a special case, they are not used to project market coverage results in general to the overall group of public radio stations. However, they are illustrative of important cases and a basis for exploring the potential effectiveness of IBOC coverage fill-in techniques.

3.1.2 Interference to Existing Public Radio Analog Translators from IBOC

This section covers measurements of translator interference susceptibility and application of that performance data to a sampling of actual public radio translators, considering neighboring full-service and translator stations on co-, first-, second- and third-adjacent channels. The results of calculated IBOC DAB interference are examined and projected to the system of translators in the U.S., which NPR's research indicates is over 600 public radio translators currently in use.

RF measurements were performed on two popular analog FM translators to provide interference susceptibility ratios that represent actual translator operation. One unit, a Crown FM30 built by Crown Broadcast of Elkhart, Indiana, is in use by a large number of public radio stations. The other unit, a Larcan FMT-25 built by Larcan USA of Lafayette, Colorado, is a new unit planned for future translator installations.

The D/U ratios were based on a weighted quasi-peak audio signal-to-noise ratio (WQPSNR) of 40 dB, which represents the minimum acceptable quality for the translator. Ratios for both analog-to-analog and 1% hybrid-to-analog interference were measured. Interference ratios for both translators were sufficiently close to average the results together for the single set of ratios listed in Table 1 - Interference susceptibility ratios for tested FM translators.

Table 1 - Interference susceptibility ratios for tested FM translators

	Analog FM Ratios (dB)	IBOC DAB Ratios (dB)
Cochannel	30	30
1st-Adjacent Channel	-4	8
2nd-Adjacent Channel	-50	-41
3rd-Adjacent Channel	-53	-49

Thirty public radio translators were randomly-selected from the population of approximately 620 to determine the impact of IBOC DAB interference. Translators were selected from both the Reserved and Non-Reserved parts of the FM band in proportion to the overall population of translators. Four of these translators were disqualified on the basis of distance between the translator and parent station, which suggests the translators are served by satellite links. The remaining 26 were first studied to identify all potentially-interfering full-service and translator stations that are cochannel, first-, second- and third-adjacent to the input frequency of the translator, which is the host station.

A list of the translators and host stations is provided in Table 2 - Study of existing (analog) and IBOC interference to FM translators.[3]

[3] Seven of the translators with the largest distances to their respective host stations were investigated through contacts to the host stations. This revealed that three translators had changed their input station since NPR's last database correction. However, the sample population was used with the listed host stations as generally representative of the relationship between translator facilities and parent stations.

Table 2 - Study of existing (analog) and IBOC interference to FM translators

Translator	Parent Station	Analog Interference?	IBOC DAB Interference?	Cause of Interference
K203AF	KEMC	-	-	
K201AL	KFSK	-	-	
K207BQ	KSOR	-	-	
K208BB	KNPR	-	-	
K210CR	KANU	Y	Y	cochannel
K211AP	KPLU-FM	-	-	
K213BB	KUSU-FM	-	-	
K216AG	KCBX	-	-	
K216BH	KEMC	-	-	
K220AE	KPBX-FM	-	-	
K220AJ	KSOR	-	-	
K220BZ	KSOR	-	-	
K234AB	KUAR	-	**Y**	1st-adjacent
K254AH	KPFK	-	-	
K269AO	KTOO	-	-	
K269AZ	KMXT	-	-	
K270AB	KLSE-FM	-	-	
K288BM	KOTO	-	-	
K294AC	KEMC	Y	Y	cochannel
W209AZ	WSLU	Y	Y	cochannel
W218AB	WCQS	*	*	cochannel
W218AP	WQLN-FM	-	-	
W220AC	WMNR	*	*	cochannel
W235AD	WVIA-FM	-	-	
W289AD	WSHU-FM	-	-	
W299AG	WAMC-FM	-	**Y**	1st-adjacent

* Marginal interference (<3 dB above cochannel target D/U ratio)

A prediction of field strength at the translator for each interfering station was performed, using the TIREM point-to-point model with the pertinent radiation in the direction of the translator. The interfering station fields were calculated at the elevation of the translators' antennas, using FCC data on file for each translator. The field strengths of the parent stations of the respective translators were determined using the same procedures as the interfering stations.

Next, a spreadsheet was built using the interfering and parent station data to determine the desired to undesired signal ratios for cochannel, first-, second- and third-adjacent channels, relative to the parent station's signal. A Scala-Kathrein HDCA-10 Yagi antenna was assumed to represent receiving antenna discrimination, taking into account the bearing of the interferers off the main axis of the receiving antenna. Interference ratios from Table 1 - Interference susceptibility ratios for tested FM translators were applied to each translator to provide a "Yes/No" result for both the analog-to-analog and IBOC DAB-to-analog cases. These results are listed in Table 2 - Study of existing (analog) and IBOC interference to FM translators along with a note about which type of interference was calculated.

The results in Table 2 indicate that two of the translators, K234AB and W299AG, would receive interference from first-adjacent channel stations, should those stations operate in IBOC DAB. This represents approximately eight percent (2/26) of the public radio translator station population. However, it is significant that three of the translator stations are predicted to receive cochannel interference under analog-only conditions, and two more are marginally below the minimum cochannel D/U ratio. The reason that some translators appear to operate below predicted interference margins may be due to greater terrain shielding from interfering stations that is greater than predicted from the digital terrain database and point-to-point pathloss model. (Of course, it may also be that some translator operations accept more interference than is assumed for a performance target or 40 dB WQPSNR.)

As a result of the number of translators with predicted interference, the actual proportion affected by IBOC DAB may be slightly lower than the calculated eight percent. Based on the data and experience with translator system design we estimate that the proportion of affected translator stations due to IBOC DAB operation at 1% transmission power is on the order of five percent.

3.1.3 Service Disenfranchisement for NCE-FM Stations on Commercial Channels

This report covers NPR's evaluation of potential IBOC DAB interference to the analog FM service of public radio stations operating on channels in the Non-Reserved (92.1 to 107.9 MHz "commercial") FM Band, relative to public radio stations operating in the Reserved (88.1 to 91.9 MHz) Band. The Non-Reserved Band channels are subject to minimum distance separations between the protected and interfering stations, assuming maximum facilities for the FCC Class of both stations, whereas the Reserved Band channels avoid contour overlap between the stations' actual facilities, which usually result in shorter spacings. This difference in allocation rules may lead to different interference effects, which this study was intended to learn.

Service Disenfranchisement for NCE-FM Stations on Non-Reserved Band Channels

To provide a statistically-significant basis, a total of 22 Non-Reserved Band stations were used for analysis, including three stations from the main DRCIA study plus 19 more randomly-selected stations as listed in Table 16. The coverages for indoor, mobile and portable service were performed on these stations using the same parameters applied to the remaining "50 Large Market" stations in the Reserved Band. These service categories are represented by three color-coded sections. The center columns list the interference-free coverage populations for analog-only as well as analog and IBOC DAB service with 1% and 10% transmission power. The population counts are listed in the five columns to the right of each station call sign and service category.

The four columns to the far right of Table 16 show various tradeoffs used to evaluate analog and IBOC DAB coverage effects, determined identically to Reserved Band stations in the Final Report. The percentage listed in **Baseline 1% IBOC vs. 1% Analog** is the ratio of **1% IBOC** population to **Analog @1% IBOC** population for each station, assuming the potential interference with all FM stations operating in hybrid digital. The **1% IBOC vs. Analog** and **10% IBOC vs. Analog** values compare the respective IBOC populations served to the **Analog-Only** population. The **Analog @10% vs. Analog** compares the population differences between **Analog @10% IBOC** and **Analog-Only** populations. Averages for all 22 stations are listed at the bottom of each category section.

The columns to the far right of Table 16 (in Section 7.4) are compared with the Reserved Band stations in the tables of the 50 Large-Market Stations, shown in the Final Report Appendix, Section 7.4.[4] Table 3, below, compares results of the Non-Reserved Band stations to the Reserved Band stations. The four center columns ("Baseline 1% IBOC vs. Analog" through "Analog @10% IBOC vs. Analog") average the data from the left columns in Table 16 and the Final Report tables for Non-Reserved Band and Reserved Band stations, respectively.

Table 3 - Averages comparing Non-Reserved Band ("Commercial") and Reserved Band ("Non-Commercial") stations

Category	Band	Baseline 1% IBOC vs. 1% Analog	1% IBOC vs. Analog	10% IBOC vs. Analog	Analog @10% IBOC vs. Analog	Analog @1% IBOC vs. Analog
Indoor	Non-Reserved	37%	36%	86%	88%	98%
	Reserved	39%	37%	86%	78%	96%
Mobile	Non-Reserved	74%	65%	121%	80%	91%
	Reserved	108%	90%	164%	75%	88%
Portable	Non-Reserved	35%	34%	95%	97%	99%
	Reserved	32%	31%	79%	94%	92%

Note: "Analog" refers to "Analog-Only" data in Table 16.

Results of the Indoor service category for "Baseline 1% IBOC vs. Analog", "I% IBOC vs. Analog" and "10% IBOC vs. Analog" are similar, indicating little difference between the stations' IBOC and analog FM service in either band. The results for Portable coverage are similar, also, except for "10% IBOC vs. Analog" service, where two Non-Reserved Band stations with unusually large coverage at 10% IBOC drive the average to 95%.

For the Mobile service category, the differences between Non-Reserved Band and Reserved Band percentages are more pronounced. This is due to the greater size of mobile coverage areas, which become more subject to interference from other stations in the region. The coverage of 1% IBOC to analog FM with 1% IBOC interference averages 74% for Non-Reserved Band stations, but this ratio increases to 108% for Reserved Band stations.

Since these percentages compare IBOC relative to analog service, the combinations are numerous. However, an additional column has been added to the far right, which allows us to compare analog with 1% IBOC interference to analog-only service. This column shows the analog mobile service population to be within 3% for both conditions, which suggests that lower percentage for Non-Reserved channels is due to increased interference to IBOC, or conversely, reduced interference to IBOC on Reserved Band channels.

The next column, "I% IBOC vs. Analog", maintains a similar relationship between Non-Reserved Band and Reserved Band: 65% to 90%, respectively. Since the interference to analog service has been removed from this data, and the relative difference remains close to the same while IBOC-to-analog interference is constant, it appears that the Non-Reserved Band's IBOC channels are experiencing slightly more interference more than the stations' associated analog service.

[4] Three stations operating on Non-Reserved Band channels were removed from the 50 Large-Market Stations table in the Final Report and transferred to Table 16, to provide a total of 46 Reserved Band stations for comparison.

The next column, "10% IBOC vs. Analog", shows percentages of 121% and 164% for Non-Reserved Band and Reserved band stations, respectively, which is a similar relationship to the "1% IBOC vs. Analog" condition. Since the ratio of "Analog @ 10% IBOC vs. Analog" is similar (80% vs. 75%), this once again indicates that the IBOC coverage may be more impacted by interference from regional neighbors.

It is worth noting the values in the last two columns alone, since they show the direct impact of IBOC operation at 10% and 1% transmission powers on original analog service. For the Reserved Band, the numbers are slightly lower than the Non-Reserved Band numbers (-5% for 10% IBOC and -3% for 1% IBOC). However, as these differences are minor and within the margin of error for the sample populations, it is reasonable to suggest that the impact of IBOC operation on analog FM service is similar for both Reserved Band and Non-Reserved Band stations.

3.2 Analog Coverage Analysis

Interference which limits public radio service areas is an inherent factor of using the electromagnetic spectrum. Data developed in this study indicates a substantial real-world loss of population coverage is inherent in the protection criteria established for the FM service in the 1940's.

For example, our tabular summaries indicate the theoretical FM analog population coverage, in the aggregate, for indoor and mobile performance among the 25 smaller market stations is eroded by 37% from existing *analog* FM stations. For smaller market stations, the coverage is smaller yet, with an effective reach for indoor coverage of only 21.6% vs. analog on average, a 78.4% deficit.

Of those 25 smaller market stations, thirteen scenarios result in less than 50% of the theoretical reach due to analog interference. And, of those, six scenarios are so seriously eroded from their theoretical reach that existing analog interference is resulting in population coverage only in the teens of percents versus reach absent that interference.

While we would hesitate to characterize this as a broken allocations and protection scheme, it may help explain why so many smaller market stations are struggling to maintain a sustainable service. And it underscores that over time the allocation protections put in place based on original receiver performance tests a half century ago have long lost validity. Whereas one might expect modern receivers to perform with much greater selectivity and less susceptibility to interference, the reality is substantial levels of interference are inherent in the vagaries of the simplified allocations rules from decades past.

The tabular results of introducing 1% IBOC service, on a universal basis, documents some adverse potential impact on analog FM service levels. On average, the population data documents that for the 50 larger markets this represents a roughly 11% theoretical loss, under worst-case "all stations on" conditions for mobile listening. This modest number under the worst-case condition is validated by the few complaints of actual interference that have been reported for introduction of FM IBOC. We phrase this as a theoretical loss as some population coverage numbers are associated with point-to-point reception values that could be in a non-contiguous service area where mobile coverage is unlikely to represent actual listening.

One percent IBOC coverage observations

Indoor and projected HD Radio portable coverage is only 33-40% of existing analog FM coverage in the 50 larger markets. In the smaller markets, chosen as "rim shot" situations, the percentage of coverage is even smaller at roughly just 20% of the analog markets.

Mobile HD coverage, however, performs substantially better, at 78% of analog in the rim shot markets, but covers approximately 89% of the analog coverage in the 50 larger markets.

Many Mobile Coverage Winners With HD at 10%, Particularly in Rim shot Markets

When turning up the sideband power to a full 10% on all stations studied, mobile coverage in the top 50 markets doubles to 162% of existing analog coverage, but with a commensurate drop from 89% to 76% in analog coverage.

For the smaller 25 "rim shot" markets, the numbers swing even wider with mobile coverage jumping from 79% of analog coverage to nearly double the analog coverage at 199% of the analog. Meanwhile, the analog coverage drops just four percent from 78% to 74%. Clearly the massing of population at the periphery of these existing station service areas could someday yield huge gains in coverage reach, but only assuming digital radios were magically ubiquitous.

For indoor coverage, in the rim shot markets, the jump to 10% IBOC would improve coverage from a mere 22% to 79%, and for projected portable reception the improvement would be even better from 20% to 94%.

For the larger 50 markets the numbers are again slightly better with the improvement in indoor coverage moving up from 39% to 89% of analog reception and for projected portable listening from 33% to 96%.

For indoor and portable reception, using the link budgets and assumptions of this study project that an all-HD future at 10% injection falls measurably short of existing analog coverage, and in the interim, would result in reductions in existing analog coverage. However, mobile reception shows potentially dramatic gains, albeit with a commensurate reduction in analog coverage in the interim.

3.3 Digital Coverage Analysis

Digital under service relative to analog *mobile* service is approximately 11% in the aggregate for the stations in the 50 larger markets, and as one might expect for the 25 smaller market "rim shot" stations, a larger 22% shortfall.

Indoor and projected HD Radio portable coverage is only 33-40% of existing analog FM coverage in the 50 larger markets. In the smaller markets, chosen as "rim shot" situations, the percentage of coverage is even smaller at roughly just 20% of the analog markets.

Mobile HD coverage, however, performs substantially better, at 78% of analog in the rim shot markets, but covers approximately 89% of the analog coverage in the 50 larger markets.

3.3.1 Many Mobile Coverage Winners With 10% HD, Particularly Rim Shot Markets

When turning up the sideband power to a full 10% on all stations studied, our prediction model for mobile coverage in the top 50 markets doubles to 162% of existing analog coverage, but with a commensurate drop from 89% to 76% in analog coverage.

For the smaller 25 "rim shot" markets, the numbers swing even wider with mobile coverage jumping from 79% of analog coverage to nearly double the analog coverage at 199% of the analog. Meanwhile, the analog coverage drops just four percent from 78% to 74%. Clearly the massing of population at the periphery of these existing station service areas could someday yield huge gains in coverage reach, but only assuming digital radios were magically ubiquitous.

For indoor coverage, in the rim shot markets, the jump to 10% IBOC would improve coverage from a mere 22% to 79%, and for projected portable reception the improvement would be even better from 20% to 94%.

For the larger 50 markets the numbers are again slightly better with the improvement in indoor coverage moving up from 39% to 89% of analog reception and for projected portable listening from 33% to 96%.

For indoor and portable reception, using the link budgets and assumptions of this study project that an all-HD future at 10% injection falls just short of existing analog coverage, and in the interim, would result in reductions in existing analog coverage. However, mobile reception shows potentially dramatic gains, albeit with a commensurate reduction in analog coverage in the interim.

For indoor reception, in the major markets, the situation is more adverse with a 60% average indoor deficit (reaching only 40% of the analog indoor population).

NPR and CPB chose the 25 smaller rim-shot markets as likely test cases where both digital underservice and impact to analog were likely to be exacerbated due to the aggregation of peripheral population centers. For smaller market stations, the coverage is smaller yet, with an effective reach for indoor coverage of only 21.6% vs. analog on average, a 78.4% deficit.

These factors put numbers to the general assessments that have been reported from the field – digital indoor coverage is unreliable except within core urban coverage areas. Like satellite radio, <u>HD Radio is an essentially line of sight limited indoor service, and an outdoor antenna or window facing the transmitter are the typical situations where service should be expected outside of urban cores</u>.

3.3.2 "Dual First-Adjacent" Deficits

As noted throughout this report, digital radio coverage and interference are highly variable and only a handful of generalized findings genuinely hold up well across the stations studied.

Seven smaller market stations, <u>almost a third of the smaller market stations, have mobile IBOC coverage that is less than 60% of the analog coverage</u>, and three of the 50 larger market stations similarly document IBOC coverage at less than 60% of the analog coverage.

These potential deficits should be addressed to assure a viable digital transition for the affected stations. In general, these stations are affected by the presence of nearby 1st adjacent analog stations on both the upper and lower channels. The heavier apparent presence of these stations in smaller "rim shot" markets is likely due to their suburban placement between nearby metropolitan communities. This places an additional challenge on resource constrained operations to achieve the benefits of digital service expansion. Additionally, since dual first adjacent stations are limiting their digital coverage, a wholesale increase in their sideband power would have a predictable highly negative impact on the adjacent analog stations. Thus, SFN on-channel boosters should be carefully evaluated for cost and audience impact on a priority basis in these markets.

Mobile HD coverage at 1% is, on average, achieving almost 90% of analog coverage. This figure is calibrated to analog noise levels at which 90% of listeners report they would continue listening. On the one hand, analog listening is likely to be maintained at greater distances for committed listeners, but on the other, the premium value associated with digital radio's lack of noise is also not factored in the data. Digital quieting has repeatedly been shown to be far more important to modern listeners than many forms of audio degradation. Presumably, modern listeners have become acculturated to digital quieting as a important benchmark of quality.

While mobile HD coverage is not markedly different from analog, as real world practitioners already know, indoor coverage for HD Radio is significantly challenged, and is documented this study as achieving only some 40% of the expected analog FM coverage (based on 80% likelihood of availability throughout the homes, offices and shopping locations studied).

Although studies such as the recent Paul Jacob's "Bedroom Study"[5] suggest less and less time is being spent at home listening to the radio, this substantial shortfall compared to analog needs attention. While indoor coverage is better than some new competitors such as satellite radio, it compares unfavorably to the analog experiences that users know, and will use for comparison with hybrid HD receivers.

Recent reports indicate that some commercial entities have separately studied and may soon recommend experimentation with substantially higher levels of sideband power of up to 10% (compared to the existing 1% power level). The NPR LABS study has documented the projected effects and found that for both mobile and indoor coverage substantial coverage improvements could be made by shifting to 10% injection -- but at a significant analog interference penalty – if completely unqualified or controlled.

In fact, the 10% elevated power study indicates a substantial improvement of over 60% in additional population reach could be achieved compared to analog coverage, but *only if all consumers had HD receivers*. For indoor population coverage, the improvement more than doubles, but still falls short, only approaching 90% of the existing analog population.

The study only contemplates the performance of existing receiver and antenna designs, factors which may be susceptible to some improvements that could help equalize indoor penetration, especially in an elevated sideband power environment. Again, this assessment is hypothetical as it assumes that all consumers have digital receivers. Such a situation would ultimately result

[5] In 2007 Arbitron and Jacobs Media conducted ethnographic research to observe young Americans interacting with technology and media in their natural habitats. See full report at www.thebedroomstudy.com/.

in the cessation of analog transmission and likely achieve substantial additional coverage gains due to the elimination of the dominant interfering analog carrier.

The question of getting from here to there without substantial penalties to analog coverage is likely a matter of successive, calculated strategies, potentially trading off some increments in analog interference risk for more digital coverage, commensurate with increases in digital receiver penetration.

4 Receiving System Performance Investigation

4.1 Receiver Performance Results

To determine the interference ratios affecting HD Radio reception, as well as other potential impairments, an RF Test bed was built to measure consumer receivers. Using threshold digital receive failure as the criteria, the measurement objectives of the receivers were:

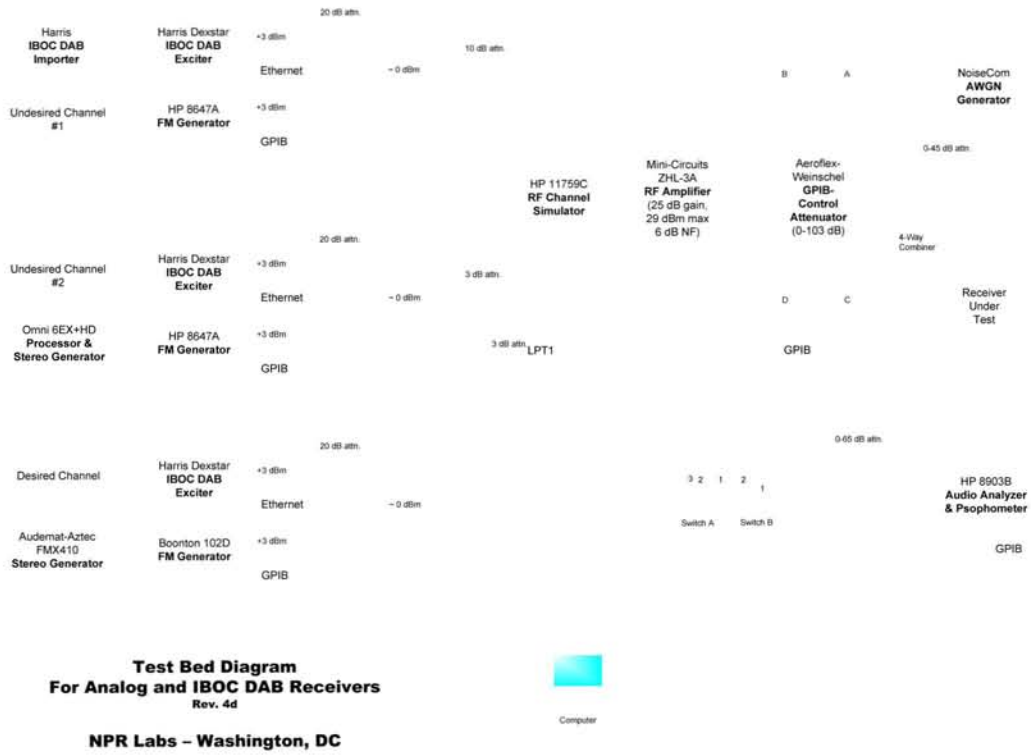
- Unimpaired sensitivity
- Sensitivity with Additive White Gaussian Noise
- Co-channel interference ratio
- 1st-adjacent channel interference ratio (single and dual)
- 2nd-adjacent channel interference ratio (single and dual)
- 3rd-adjacent channel interference ratio
- Tests of the above with analog FM interfering signals as well as hybrid interfering signals
- Tests of the above with Raleigh fading on either the desired channel, interfering channel, or both

For the hybrid signal generation systems a Harris Dexstar HD Radio exciter was combined with a Hewlett Packard 8647A FM generator. The Dexstar and the FM generator operate at a constant +3 dBm output; with a 20 dB attenuator connected to the Dexstar, the combined output level of the system was approximately 0 dBm. Three of these systems were used; one for the Desired Channel and two for Undesired Channels #1 and #2. All of the HD Radio exciters were connected to a central GPS antenna on the roof of NPR Labs. A 10 MHz GPS-derived signal from one Dexstar was used to synchronize the other RF test instruments.

As shown in the simplified diagram of Figure 1, the signal generator systems were connected to a Hewlett Packard 11759C Channel Simulator, which was used to introduce Rayleigh fading. A two-channel RF attenuator system by Aeroflex-Weischel provided control of the RF levels over a 0 to 103 dB range in 1 dB steps.

System levels were made up by two high-performance RF amplifiers made by Mini-Circuits so that the maximum input level to the Receiver Under Test was approximately 7 dBm on any FM carrier. This is equivalent to a dipole field strength of 109 dBuV. Higher input powers to the receiver were found to be necessary to cause 2nd and 3rd adjacent reception failure with some receivers, but the dynamic range of the system was a good tradeoff between noise floor and high-level receive conditions.

Figure 1 -Receiver test bed for analog and IBOC DAB receiver measurements



A photo of the RF Test bed is shown in Figure 2. Not visible is the computer workstation that was networked to the instrumentation. This computer runs MATLAB software to automate the measurements. (It was decided early in the project that the number of tests would be cumbersome to collect manually. As we learned later, as the number of measurement points climbed, automation was a fortunate decision.)

An Ethernet switch is connected to the Dexstar exciters, to control emission and frequency, and to an Audemat-Aztec FMX480 stereo generator on the Desired Channel generator system. A GPIB network was set up to communicate to the other instrumentation. A Hewlett Packard 8903B audio analyzer was included in the test bed for audio SNR testing and generation of audio test signals under MATLAB control.

To the left of the tall racks, and just visible in the photo past our lab intern, is a Ramsey Electronics STE5000 shielded test enclosure. Used with double-shielded coaxial cables, this cabinet allows us to test unshielded consumer receivers without signal leakage from broadcast stations and avoids the need for a large screen room.

An Additive White Gaussian Noise Generator using the NoiseCom NC6110 noise source was available for noise impairment tests. Noise levels of 30,000°K and 300,000°K (degrees Kelvin) were chosen for sensitivity impairment tests. These levels were proposed by iBiquity Digital, which commissioned two consulting firms to determine the noise level caused by co-channel analog interference. The noise level was approximately 30,000°K, which is equivalent to a field strength of 15 dBuV.[6] While iBiquity intended this noise to be added for analog compatibility testing of IBOC DAB, AWGN is a good representation for outdoor environments in which to test HD Radio receivers. For additional comparison, a level 10 dB higher (300,000°K) was included in our testing.

Figure 2 - The RF test bed in use

To date, a total of 17 HD Radio receivers have been measured on the Test bed. The types represented are: after-market car radios, hi-fi tuners, professional tuner/monitors, and table radios. As mentioned earlier, sensitivity was performed for all receivers automatically by the test bed with two levels of Gaussian noise as well as with no added noise. Additionally, several receivers were tested manually to verify the results with Gaussian noise and Rayleigh fading that were supplied by iBiquity to the NRSC and ITU.[7] The iBiquity results are represented using block error ratios. The threshold of muting was used to estimate performance (consumer receivers do not provide a means of measurement BER); however, good agreement was found between the production receivers and the published results at the highlighted BER values.

The final results of the receiver testing for analog FM reception are listed below. Table 4 lists the desired-to-undesired (D/U) ratios at which a 40 dB weighted quasi-peak signal-to-noise-

[6] iBiquity Digital Corporation, *The FM Broadcast Band: Service Area Noise Floors in the US*, (presented to NRSC TPWG 11/09/2000).

[7] ITU-R Question 107/10, Document 6/203(Rev.1), *Systems for terrestrial digital sound broadcasting to vehicular, portable and fixed receivers in the frequency range 30-3 000 MHz*, 8 March 2002.

ratio (WQPSNR) is attained for tested mobile receivers. The IBOC DAB measurements show the analog FM impairment with hybrid digital interferers at 1 percent and 10 percent transmission power. Tests were performed at desired signal powers of -50, -60 and -70 dBm to determine any signal level-dependent effects on D/U ratios. Since -50 dBm is equivalent to a strong received signal well inside the protected contour of FM stations it is an unlikely occurrence for the listed interference conditions. The results at both -60 dBm and -70 dBm are more likely to correspond to actual signal powers at which interference could occur. Table 5 and Table 6 list the D/U ratios for indoor and portable receivers, respectively. Measurements marked with an asterisk (*) are estimated values due to ranges beyond the test bed capabilities, excessive receiver instability, etc.

Table 4 - D/U ratios for mobile receivers at 40 dB WQPSNR

Interferer	**Analog**		**IBOC DAB @1%**		**IBOC DAB @10%**	
	-60 dBm	-70 dBm	-60 dBm	-70 dBm	-60 dBm	-70 dBm
Cochannel	34	31	34	31	29	25
1st-Adj.	-9	-8	12	10	21	20
2nd-Adj.	-51*	-57	-50	-57	-50	-52
3rd-Adj.	-51*	-60*	-50	-57*	-50	-52

Table 5 - D/U ratios for indoor receivers at 40 dB WQPSNR

Interferer	**Analog**		**IBOC DAB @1%**		**IBOC DAB @10%**	
	-60 dBm	-70 dBm	-60 dBm	-70 dBm	-60 dBm	-70 dBm
Cochannel	34	34	34	34	29	25
1st-Adj.	1	0	13	12	23	23
2nd-Adj.	-45	-46	-32	-36	-16	-23
3rd-Adj.	-47	-48	-38	-42	-22	-30

Table 6 - D/U ratios for portable receivers at 40 dB WQPSNR

Interferer	Analog		IBOC DAB @1%		IBOC DAB @10%	
	-60 dBm	-70 dBm	-60 dBm	-70 dBm	-60 dBm	-70 dBm
Cochannel	21	21*	18	16	29*	25*
1st-Adj.	4	-1	0	-1	23*	23*
2nd-Adj.	-38	-42	-22	-22	-16*	-23*
3rd-Adj.	-42	-46	-35	-41	-22*	-30*

It is notable that with mobile radios the first-adjacent D/U ratios decline by approximately 20 dB with 1% IBOC, relative to analog-only interference. The high rejection of analog-only interference is due to the selectivity of mobile radios. However, the IBOC DAB carriers of a first-adjacent interferer fall within the desired channel, and thus have a great effect on impairment. For 10% IBOC, the interference power increases 10-fold, thus the D/U ratio declines by 10 dB.

The D/U ratios are used directly in the coverage map studies, without alteration. We believe the maps produced as part of the DRCIA project represent the industry's first depictions of system-wide service that reflect actual consumer receiver behavior.

4.2 Conclusions on Potential Receiver Performance Improvements

The 15 consumer HD Radio receivers tested for this project were found to have relatively uniform performance, compared to the 35 consumer analog FM receivers. This may be due in part to the higher cost of the current HD Radio receivers, which allow for higher quality design in stages of the radio that affect RF performance. Most of the receivers also share a common Texas Instruments digital signal processor, which performs the functions of IF bandpass filter, demodulator and data decoder.

The consumer HD Radio receivers have performance levels for sensitivity and interference rejection that are close to theoretical parameters for the COFDM system used for HD Radio. As discussed in the IBOC Receiver technical report, appended hereto, there is little opportunity for receiver improvements that would substantially reduce the difference in coverage between IBOC and analog FM coverage.

On the other hand, there is a possibility that cost pressures will cause some manufacturers to reduce the quality of front-end design and components used in HD Radio receivers. This could result in degradation in service, rather than potential improvement. NPR Labs will continue to test and report on the performance of new consumer radio models in order to identify problems areas and where possible work with manufacturers to maintain high quality receiver performance.

Based on our experience with receivers and public practice, an area of potential improvement is in the antennas used. We had success in helping convince manufacturers to pack the "T" antennas with their units. (As reported in the Indoor Antenna Test Report, attached, this antenna performed well, especially in comparison with its low cost.) Raising the input signal level of HD Radio for indoor service, while avoiding overload and noise problems, is an important potential improvement.

5 Projected Economic Impacts

5.1 Caveats on Limits of Threshold Analysis

The impact on stations economics is drawn from (1) evidence of any positive or negative effects seen by stations, as well as (2) inferences about potential effects based on the interference and coverage data generated in these studies. The large variability in local station economics means that field reports require repetition to be evidence of a credible trend.

To date, NPR Labs has received no reports of an adverse economic impact from any loss of analog listening from the commencement of HD Radio operations. In fact, we have received only two reports of an interference impact beyond the protected contours to FM listening. In cases beyond the protected contours, translators are the generally accepted means of serving nearby areas, and have been activated on many occasions to supplement weak signals.

Aside from the expected capital, human resources, and electrical consumption investments of commencing HD operations, the economic upside of HD commencement to date has been mostly developmental. While not insignificant, they are hard to quantify, with several managers reporting that HD multicasting has avoided divisive programming choices, and helped both stabilize and grow loyalty to the station among both long time and new listening groups. Some managers have also reported modest increases in underwriting revenues attributable to increased multicasting inventory.

5.2 Current and Future Impact: The “Economics of Signal Sensitivity”

<u>Correlating Listening Locations to Signal Strength</u>

The engineering studies at the heart of the DRCIA project have sought to document the complex, interconnected interference and coverage issues associated with the introduction of HD Radio. Correlating the predictive power of signal strength on audience impact will inform the level of sensitivity appropriate regarding IBOC introduction. Thus, NPR sought supplemental data to calibrate the signal-to-noise tolerance findings within existing real-world listening data.

Arbitron and other audience measurement companies are viewed as providing the best snapshot of aggregate radio listening available. With only a reported roughly ½ million HD Radios currently in the marketplace it is clear that over 99% of radio listening is to the analog service. Accordingly, NPR’s Audience Insight Research unit was consulted to see if a pattern of listening could be established against existing analog signal quality.

Numbers of diary mentions were made available on ten randomly-selected public radio stations, as shown below, in descending order of total mentions.

WBUR, Boston
WAMU, Washington
WNYC, New York
WAMC, Albany
KPCC, Los Angeles
WBEZ, Chicago
KERA, Dallas
KUT, Austin
WFYI, Indianapolis
KLCC, Eugene

The data represented 4,796 diary mentions, ranging from 227 mentions for KLCC to 850 for WBUR.

Methodology and Study caveats

Zip codes for all of the 4,796 diary mentions were plotted in GIS, showing numbers of respondents associated with each station within that zipcode. An overlay of FCC computed signal strength was derived with statistics correlated to the listening distribution layer and transferred to an excel spreadsheet. Small anomalies were inherent in achieving an exact visual match between the FCC 60, 50, and 40 dBu contours and the granularity of zip code listening. A series of successive test matches were conducted with markets showing multiple zip code listening densities at the boundaries of specific contours. Those test matches revealed deviations on the order of 1-2% being observed with the final match being the one used in data compilation.

The data used is the zip code of the reporting listeners, and that zip code is associated with reference coordinates of the main post office for that zip code. Some zip codes, especially in more rural communities can cover wide areas which would have significant signal strength variations from that shown for the reference post office. It is suspected that for a sample of this size – approaching 5,000 data points that such errors are effectively randomized, but we have no way to prove this.

No knowledge of the actual location of diary listening is available, nor the type of receiving device employed. For example, for the listening that is attributed to locations beyond the 40 dBu contour, we do not know if the listening was achieved by rooftop directional antennas, or internet streaming, listening to a translator, or merely a listening notation associated with a long-distance commuter living in that distant community.

Results

Among these ten stations, the aggregate data reveals that just over three quarters of all zip-code reference coordinates (75.7%) were inside the 60 dBu signal contour. Conversely, almost one quarter of listener mentions was from beyond the protected contour.

Roughly 12 percent of listening was in the next ring of signal strength out to the 50 dBu contour, and 6 per cent of listening was associated with the next weaker ring of signal strength, out to the 40 dBu contour, and finally, another 6 per cent of listening was associated with zip codes beyond the 40 dBu contour. See Table 7.

Within the aggregate results some variations are noted. The ratio of "protected" listening to total zip code listener mentions varied within a 17% window between 85% for stations WBEZ and KUT, and 68% for WAMC. Stated differently, the "protected listening mentions" were within +10% to minus 7% range of the average of 75.7% and six of the stations had higher than average rankings.

Table 7

Station	60 dBu	50-59 dBu	40-49 dBu	Below 40 dBu	Total	Protected Ratio	Station	60 dBu	50-59 dBu	40-49 dBu	Below 40 dBu	Total
WBUR	615	122	55	58	850	72.4%	WBUR	615	122	55	58	850
WAMU	587	96	73	53	809	72.6%	WAMU	587	96	73	53	809
WNYC	489	142	40	26	697	70.2%	WNYC	489	142	40	26	697
WAMC	332	84	47	24	487	68.2%	WAMC	332	84	47	24	487
KPCC	312	43	19	17	391	79.8%	KPCC	312	43	19	17	391
WBEZ	330	27	11	19	387	85.3%	WBEZ	330	27	11	19	387

With roughly half of average total station revenue based on listener contributions, potential interference compromises, even well beyond the dominant "protected" signal contour, could have significant negative consequences to station revenue, and for struggling stations represent a serious challenge to station viability. Stations must be educated to the risks of such potential interference consequences, particularly as they might affect their individual operation, and have the information and means to elect signal optimization strategies that will reinforce, rather than erode their economic base.

Figure 3, below documents the raw diary mentions by signal strength contour.

Figure 3 - Public radio listening by signal strength

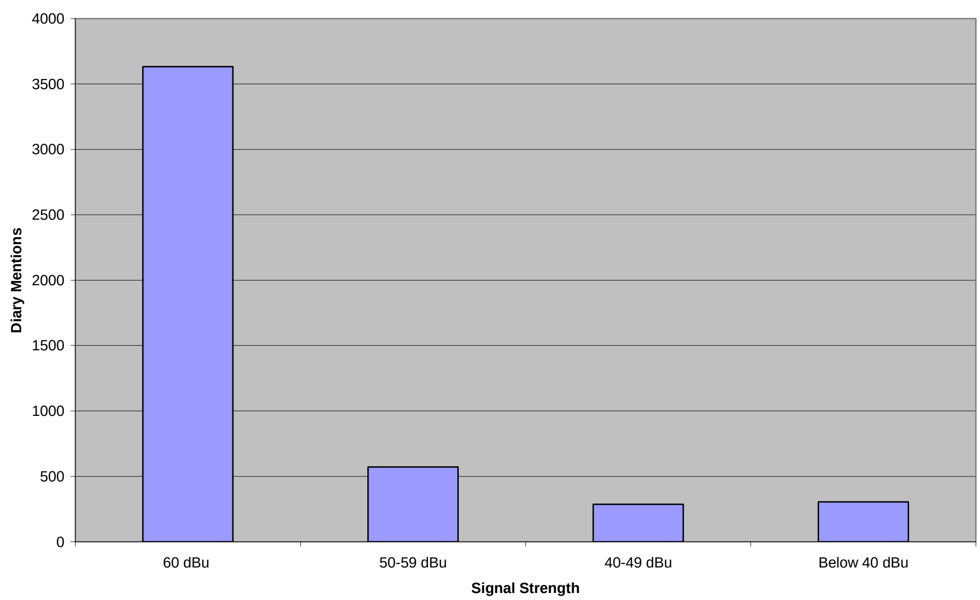
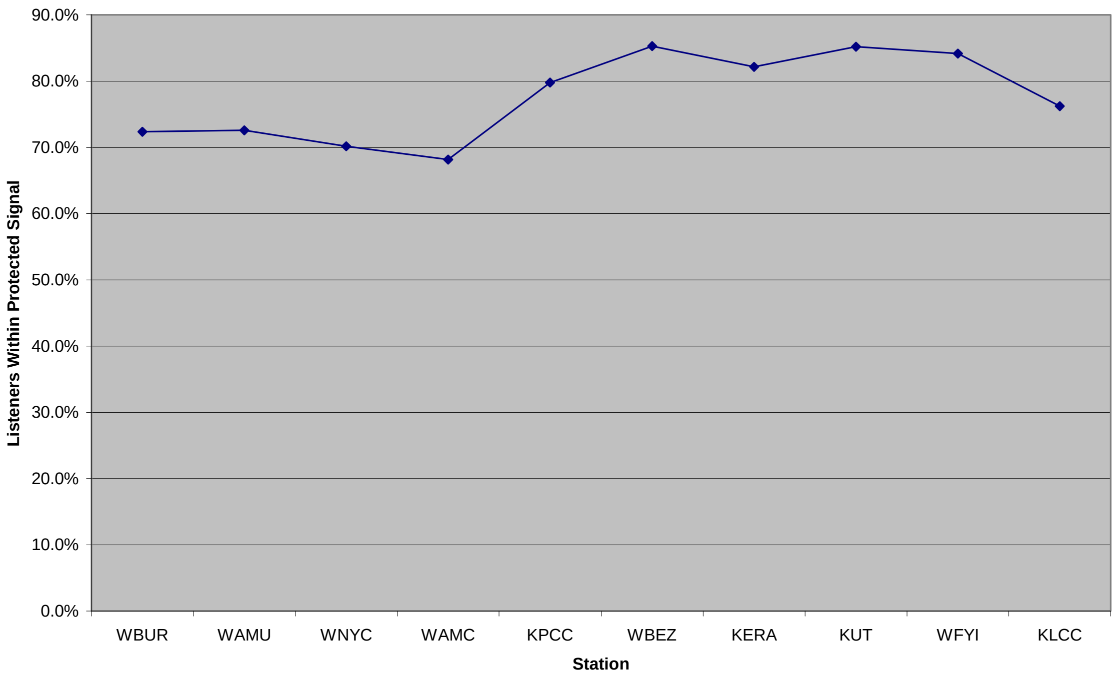


Figure 4, below, details the percentage of zip code diary sources within the 60 dBu contour.

Figure 4 - Protected contour listeners



The inference of this data could be suspect at lower signal strengths based on the inherent ambiguity in actual listening locations with the imputed post office reference coordinates for the diary entrant's zip code. Additionally, some listening might be via web streaming, rather than to the over-the-air signal. Moreover, there could be some listening at these distances that *are* over the air, but which are to translators, and thus not associated with the signal of the parent station.

This data was shared with engineers at several of the identified stations. The reported listening locations were generally viewed as likely actual listening locations, due to knowledge of actual listening in those areas (thanks to favorable terrain and higher than FCC predicted signal strength) or listeners known to be listening in those communities with directional antennas.

Correlating Donors to Signal Strength

Data to corroborate the listening data was sought from several stations concerning the zip codes associated with the station's database of donors. Data for a few stations was disqualified due to apparent contamination by commingling with university licensee donors uncorrelated to the station's donors. However, data for eight stations was obtained that appears valid and which correlates well to station signals. In total, approximately 190,000 donors are represented by the underlying data.

For these stations the reference 60 dBu contour encompassed between 79% and 95% of reported donor zip codes, as shown in Figure 5, below, which details the distribution between contours.

In comparing Figure 6, below with Figure 4, this data indicates a slightly stronger predictive association between signal strength and donors versus the Arbitron listening data. Additional donor data would be useful in determining whether the roughly 10% higher correlation among donors within the protected coverage contour holds up.

Figure 5 - Donor zip codes by signal strength

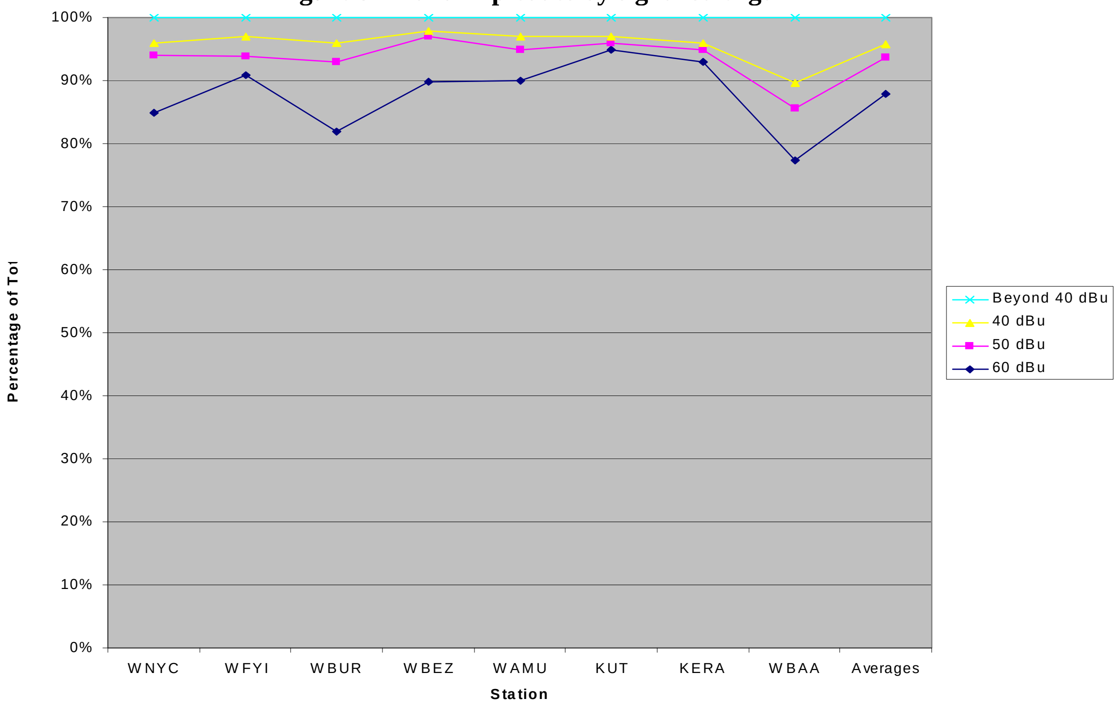
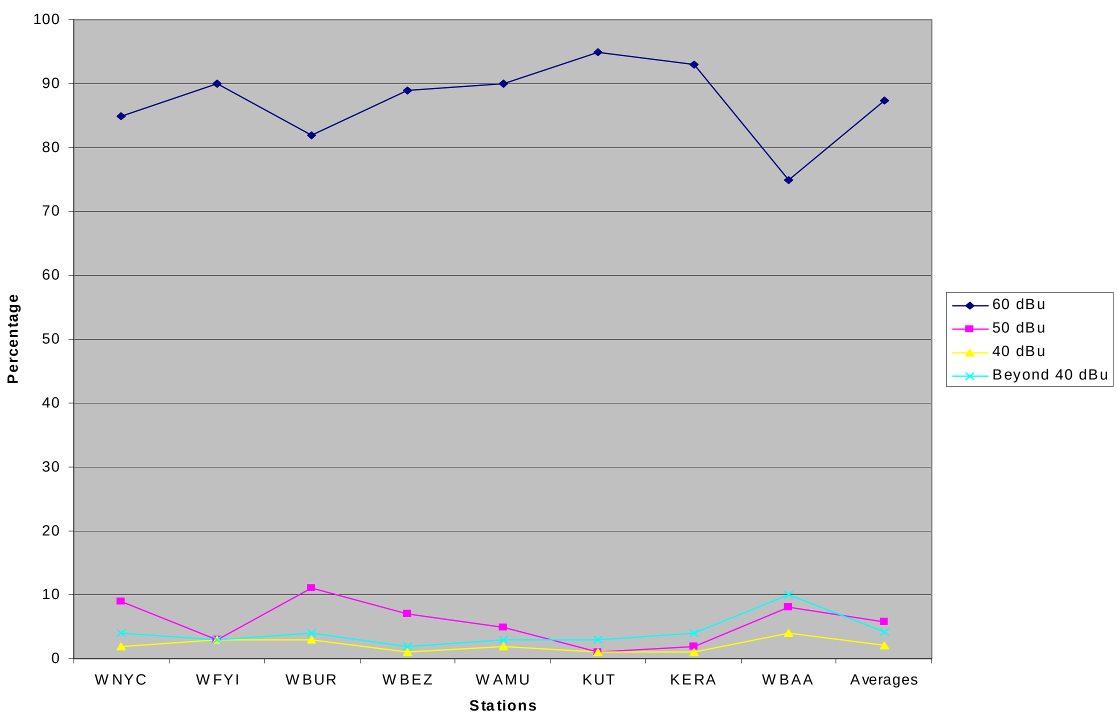


Figure 6 - Individual Contour Donor Totals



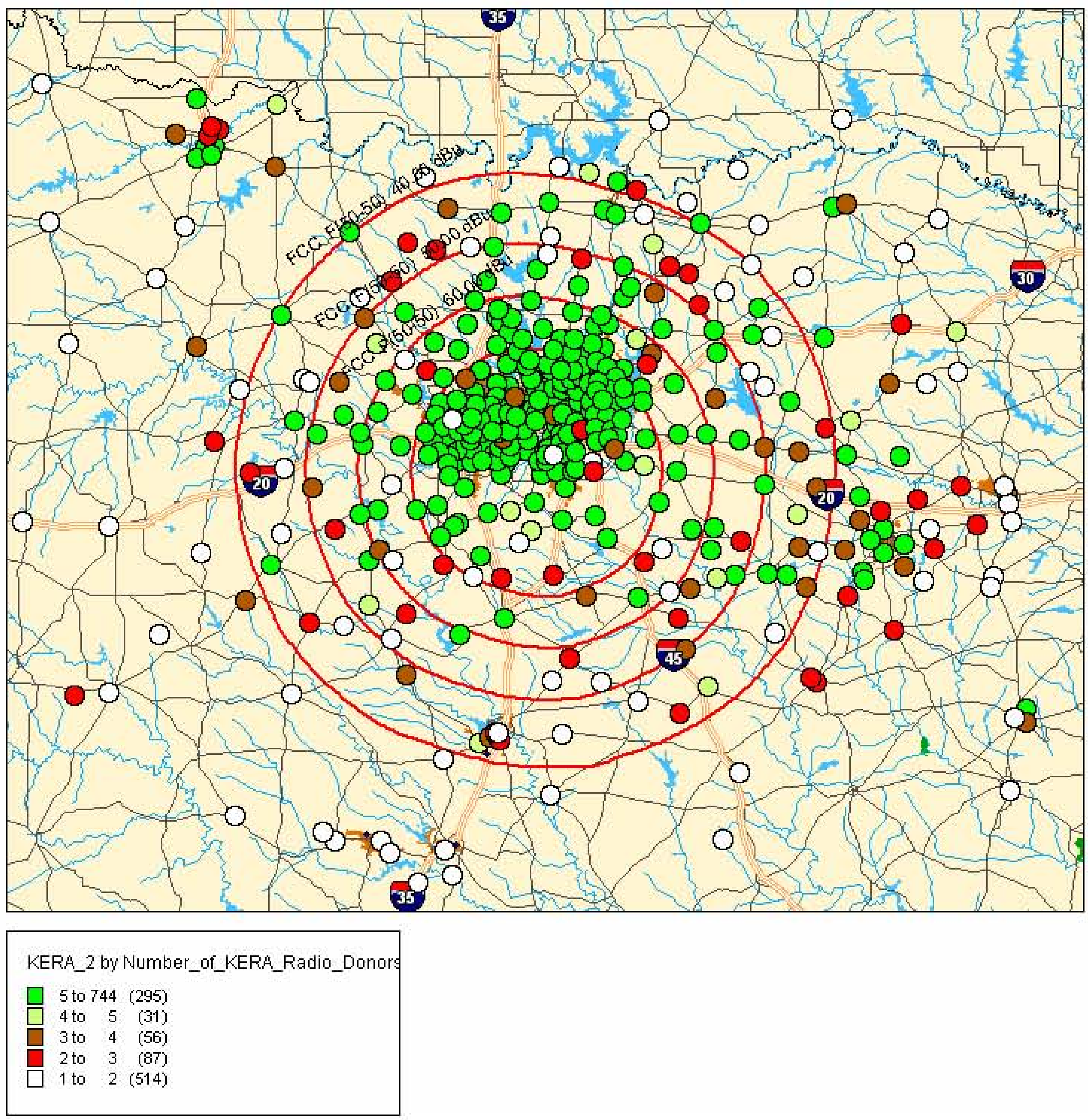
Summary

The close approximations between Arbitron reported listening and station donor clearly document that economically significant listening is occurring outside of the protected contours which we believe any well-informed station management would seek to

Figure 4, below, shows the same data, with individual contours shown separately, rather than cumulatively (as in Figure 5).

Some clustering was observed near interstates at beyond the 40 dBu contour, indicating some donor zip codes are likely attributable to long distance commuters who have chosen residence by "driving to affordability". See Figure 7, below:

Figure 7 - KERA GIS Coordinates for Arbitron Listener Zipcodes (Note the distant clustering around I-30 and I-20 to the East, and I-35 to the South)



5.3 Potential Transmission Improvement Strategies

iBiquity Digital developed high standards for the generation and transmission of its HD Radio signal, which have been adhered to by manufacturers. This has left relatively little room for improvement in existing transmission equipment. However, one area of improvement that is essential to support single-frequency network operation is not on iBiquity's scheduled improvements: the synchronization of data coding at Layer 1 in the exciter. At Layer 1 the data is processed for error correction, formed into blocks with headers and sent to the modulator. Currently, this process occurs independently by each exciter, even if transmitting the same audio on the same station. New system-level code would need to be developed and tested to support time-synchronized framing of this coded data, so that two transmitters could be locked in step by GPS-clock timing. This capability would enable a booster to match the data timing of its primary transmitter, ensuring that single frequency networks could be operated dependably.

Another potential improvement, asymmetrical sideband operation, is discussed more fully in Section 6 of this report. It depends partly on testing and development outside of iBiquity Digital and is another recommendation for future CPB support.

5.4 Extrapolated System-Wide Coverage Optimization Cost Projections

The basic infrastructure of digital transmissions has represented substantial, continual investments across public broadcasting. Just as the Advanced Television Systems activity is now in its 25th year, the conversion to HD Radio appears on a similar multi-decade path towards completion. Completion is a destination, and matter of definition. On the nationwide scale of public broadcasting, it is always a staged undertaking.

The history of broadcasting shows that there are always continuous improvements being made, whether it is fundamental shifts such as the development of FM, UHF, DTV or HD Radio, or significant refinements like stereo, color, magnetic tape, digital techniques. Every decade since broadcasting's inception has seen successive technology introductions, most of which required many years to achieve prominence in the marketplace.

The DTV transition for public television has meant continuous investments in channel reassignments, implementation of low power transmissions, high power transmissions, digital master controls, multicasting facilities, and HD satellite distribution. Now, mobile video applications and equipment are poised to represent a new and important need, along side the archival infrastructure to yield significant innovations in content creation. Collectively, these investments are now just beginning to deliver the quantum leap forward in new public service offerings that were the original vision and impetus for the shift to digital transmissions.

<u>The timeline of the HD Radio transition will likely follow three distinct stages</u>.

We are currently in the first phase of hybrid operations – *the launch phase*. This launch phase will naturally draw to a close with the substantial completion of the initial 1% IBOC build out that is on track for 2011-2012 across the public radio system. This timeline will coincide with the shift to HD Radio dominance in radio receiver manufacturing. The current shift to digital IF's and high density DSP technology will be substantially complete by 2012 and result in nominal costs for OEM automakers to embrace HD as the defacto radio offering of new vehicles in those model years. BMW has recently been joined by Ford and Volvo as the first automakers to shift to HD Radio offerings. OEM suppliers are already reporting that all model year quotes for 2011 to 2012 include quotes for HD Radios.

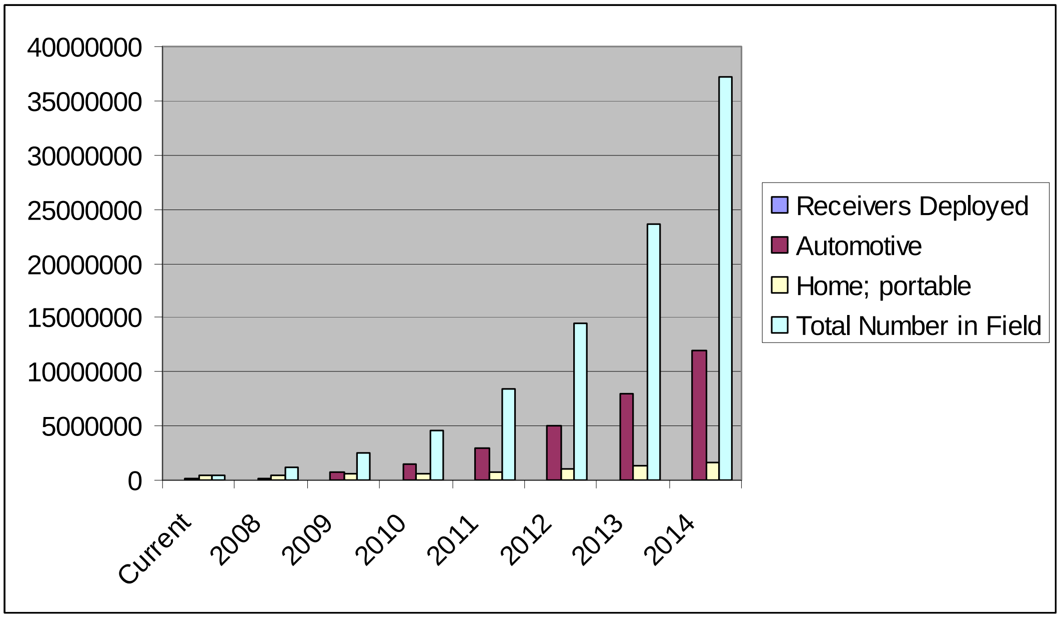
The second phase of the HD Radio transition will be marked by the commercial broadcasters' completion of the digital infrastructure, and the *optimization phase* of ubiquitous indoor signal replication. This phase is expected to transpire between 2010 to somewhere near 2013.

By 2020, the third and final phase – the *all digital phase* – will be poised for introduction based on substantial completion of broadcaster implementation as well as ubiquity in receiver manufacturing. While we can not foresee what factors will prompt federal authorities to mandate the cessation of analog broadcasts, it is likely that such an event will occur at a defined level of critical mass in receiver deployments, and has been repeatedly mentioned in FCC IBOC rulemakings to date.

Receiver Penetration – Key to the Transition

In recent months, announcements of automotive OEM support has increased. BMW has been followed by Volvo, Ford, and just this week, Mercedes and Hyundai. A total of over 50 automotive series lines across 11 automakers are reportedly committed for introduction between now and 2011. According to sources at consumer electronics automotive suppliers, by 2011 the automakers' shift to higher DSP capacity and digital IF's will slash duplicative production costs for HD inclusion. Their projections are that in this timeframe HD Radio will become the defacto dashboard radio receiver. While there has been slow growth in home unit sales, and the first portable receivers are slated for introduction for the 2008 Holiday season, the chart below, projects a mere 15% growth rate outside of automotive channels, and conservative estimates of well under 50% penetration across auto series commitments. Under this project 2012, just four years from today is seen as the breakthrough to over 10 million units in the field, the number typically associated with achieving mass market penetration, and the point at which the growth curve typically accelerates given favorable conditions.

Figure 8 - Deployment of consumer radios by year



<u>Optimization Costs – SFN Booster Approach</u>

The significant shortfall projected for Indoor HD Coverage at 1% IBOC lead to obvious conclusion that greater indoor signal density is needed. While elevated sideband approaches are being contemplated by some in the radio industry, the data developed in this study indicates substantial adverse analog interference tradeoffs would result at many stations from an unqualified increase to 10% sideband injection if all stations were transmitting at 10% injection.

The prospect of a Single Frequency Network, on-channel, digital only booster has been considered in earlier phases of this study and shows promise. Notably satellite radio service providers also rely on boosters to improve mobile coverage in major markets, as well as achieve some measure of indoor coverage. This "cellular approach" to broadcast transmission systems is a key design feature of other digital radio system deployments, such as the Eureka 147 system.

To calculate potential public radio system wide costs, NPR LABS undertook an analysis of half of the stations in the 50 larger markets, and using a reasonable fill-in contour projection of some 5 miles in radius, analyzed the indoor shortfall for HD Radio at 1% versus existing analog indoor coverage using the same noise limited criteria for acceptable service. By eliminating fill in boosters in areas with relatively low population density, the study found that, on average 6.5 SFN boosters would be required to substantially replicate the indoor analog coverage areas.

This data was added for a projection of potential optimization needs. Tiers of optimization priorities were established with the most serious shortfalls warranting first priority, presumably on the same first applicants, first funded approaches with likely similar priorities established for years in which demand might exceed available matching program funds.

Table 8 - Projected optimization funding needs

	2008	2009	2010	2011	2012	2013	2014
Basic Conversion	7,000,000	7,000,000					
Optimization Priority 1 Stations (445)			15,000,000	15,000,000	6,156,250		
Optimization Priority 2 Stations (181)					8,843,750	5,862,500	
Optimization Priority 3 Stations (198)						10,615	
Translators		2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
DFA Station Vulnerability Investigation	3,000,000						
SFN Booster Field Tests	1,500,000	3,000,000					
Estimated R&D	1,500,000	1,000,000	750,000	750,000	750,000	500,000	
Annual Subtotals	13,000,000	13,000,000	17,750,000	17,750,000	17,750,000	8,373,115	2,000,000

Table 8 reveals a reasonably good temporal match as HD receivers achieve higher market penetration figures. Priority 1 Optimization Stations represent 54% of the stations, Priority 2 stations are an additional 22%, and the Priority 3 stations comprise the remaining 24% of public radio FM stations. For the Priority 3 stations only 4 SFN fill-in boosters were allocated for each station since the indoor coverage deficits are smaller. A booster cost of $25,000 each was projected with the matching funds set to 50% of actual core costs. It must be emphasized this is a funding scenario estimation, since no SFN solution has yet been validated through an Independent Demonstration of Viability (IDOV).

Funds are also recommended for field investigations of the most serious potential dual first adjacent analog signal impairments suggested by this study. Although reports have yet to surface of this nature, the severity of projected “worst-case, all-on” impact in several markets warrants priority investigation.

It should also be stressed that transition completion costs could vary significantly and that alternate optimization strategies could appear with different costs, benefits and tradeoffs. Also important is that individual stations will assess their needs differently than the engineers who reviewed their IBOC indoor coverage models and identified numbers and locations for potential SFN boosters. The shifts identified by current audience researchers associated with declining in-home listening could cause some stations to place a lower priority on full SFN optimization solutions and greater emphasis on consumer education concerning receiving antenna systems, similar to the programs currently undertaken by DTV broadcasters.

Should an approach emerge which could minimize the deleterious impact of elevated IBOC sideband power, SFN potential needs might be minimized, and permit shifting of funds toward the significantly greater mobile HD coverage population gains seen for elevated IBOC.

6 Conclusions and Recommendations for Further Study

Over a year was spent painstakingly developing a previously non-existent prediction algorithm that would (1) accurately predict any stations' HD Radio coverage and (2) compute the potential loss of analog population coverage if all stations were operating in HD Radio both at the existing 1% coverage, as well as at the recently suggested 10% elevated carrier level.

The prediction methodology grew out of the detailed receiver performance testing, was validated by carefully selected field tests, and refined over many months to achieve an unprecedented, highly accurate "ground level" prediction system. The complex analysis required automating the point to point prediction systems and separately overlaying census data to determine likely population effects under independent scenarios. In all, millions of individual data points from the field and laboratory were studied. The results exceeded our expectations: an excellent predictive algorithm for HD coverage, despite the uncorrelated impact of adjacent digital sideband power overlay.

In extensive collaboration with ITS in Boulder, we have been able to map and count the population effects on analog and HD systems under a variety of conditions. Each public radio station has been mapped for worst-case, "all on" hybrid conditions across six scenarios.

While minimal harm appears to be currently occurring to either analog listening or economics from the introduction of HD Radio at 1%, there are significant benefits occurring for the many station managers who have commenced multicast operations. Divisive factions within many station communities have been assuaged by the commencement of 7/24 dedicated program channels, and underwriting increases have been reported by many stations for multicast inventory.

One testimonial to the local benefits of HD Radio is offered in these comments from John Weatherford, Senior Vice President and General Manager of Public Broadcasting Atlanta:

> "Here in Atlanta, with the combined classical and NPR format of WABE, three HD Radio channels have been a remarkable success. We frequently bring in major donors to visit the station. When we demonstrate the three HD channels, they are virtually speechless. They can't believe they now have three WABE channels to choose from and that (other than the one-time purchase price of the radio) it's free – no monthly fees. Every listener and donor with whom I have ever conducted a demonstration asks many questions about choices of radios and places they can buy them; then, every one immediately runs out and buys an HD radio. I get virtually the same reaction throughout the year as I speak to dozens of civic and community groups. Frequently, upon hearing about WABE's HD offerings, the reaction is: "Why would anyone want satellite radio?"
>
> One other example: Before I arrived, there was a group of more than 700 serious WABE listeners – the Atlanta Public Radio Initiative – who had been advocating for changes in the station's format to include more news and information product. The relationship between this group and the station had become somewhat contentious. APRI was seriously motivated to achieve their goal of more news and information programming; classical music listeners did not want to give up any more of the last free source of daily classical

> music in Atlanta. Seeing the promise of HD, I met several times with the APRI steering committee, urging them to seriously consider what HD Radio could offer here in Atlanta.
>
> The final result: APRI not only embraced the new technology and services; they organized an HD Radio focused effort to raise (initially) $2,500 for a challenge grant for WABE's Fall 2006 Pledge Campaign. While their original goal was $2,500, APRI ended up contributing more than $6,500 as a challenge grant that stimulated more than $15,000 in that hour of the drive – and their group came in to man the phones as volunteers! Multiple HD Radio choices here in Atlanta on WABE turned what had been a potentially negative situation into a very positive continuing relationship. A number of that group have become members of our Cornerstone Society (donors at the $1,000/higher level) and return to the station several times a year to participate in our Insider Edition monthly events."

At the same time, this study does document significant under-service of digital versus analog indoor (and future portable) coverage. To fully take advantage of the digital transition, the study has analyzed the potential coverage benefits of alternative strategies such as single frequency network boosters (aka on-channel, digital-only boosters), sideband power elevation, and potential improvements in receivers and antenna systems. No single strategy offers a magic bullet for expanding HD coverage, while minimizing analog interference impact. Each station's situation is unique, and its optimization strategies must be tailor-made.

Finally, in the aggregate, the costs to improve notable shortfalls in digital coverage, while minimizing and managing analog interference, are not insignificant and could approach a doubling of the original HD transmission cost projections.

This study has generated a vast amount of new data to inform the consequences and future directions of public radio's transition to digital radio broadcasting. This volume of information is subject to many observations, but we believe the following are important and incontrovertible conclusions.

Among the important caveats that should be reiterated are that the "impact" tabular results of coverage summaries and economic factors found in the Appendix have been intentionally constructed to describe "worst case" scenarios. That is, when the impact of 10% IBOC is shown to existing analog service calculations, it assumes that all existing stations affecting the subject facility have increased their IBOC power by a full 10%. Currently only 1,800 stations – roughly 14% of US broadcast radio stations are operating in HD Radio, thus the likely real-world impact of elevated interference percentages would be expected to be dramatically less for many stations for some time in the future.

Should the industry make a complete conversion to HD Radio, as a result of market, consumer and other factors, the adverse analog impact from elevated IBOC levels could approach the worst case impact we have calculated, but would likely be affecting a steadily declining number of remaining analog receivers.

Axioms of the Digital Radio Coverage and Interference Assessment Study

1. Mobile HD Radio Is Substantially Similar To Interference-Free Analog FM

Among the most significant findings of this study is that listener tolerance for noisy signals requires a fairly high level of analog service. Our cumulative experience with several years of digital audio subjective assessment testing is that listeners more readily tolerate minor digital audio artifacts, such as compression effects and brief dropouts, but have apparently become increasingly sensitive to continued listening of audio services unsuitable that have moderate levels of analog noise or interference. (This applies as well, of course, to IBOC DAB impairments to analog reception.) While committed analog listening can certainly occur at distances greater than is typically achieved by HD Radio at 1%, the data shows that these are clearly inferior audio channels that will result in measurable tune out among typical listeners.

2. Existing HD Radio Power Levels Are Not a Substantial Threat to FM Analog

The worst-case "all stations on in HD" data shows an average of single digit percentage losses to the population reach of the analog FM stations studied in detail. The modest level of impact was remarkably similar between the larger market stations and smaller market ("rim shot") stations, with only a few stations showing markedly higher potential interference impact. On balance, our conclusion, including our data that indicates between 15% and 25% of listeners may be based beyond the protected 60 dBu contour, is that analog FM listening is not being subjected to the risk of any substantial decline due to the introduction of 1% IBOC.

Primary Conclusion #1:

Considering that 1% mobile HD coverage is quite comparable to the quality analog reception, and is not causing a significant adverse impact on analog listening, continued support for the CPB FM digital conversion program appears quite sound and should continue.

Documenting and safeguarding, to the extent reasonably practical, the "power upgradeability" for new applicants could be a useful CPB planning factor for future regulatory policy developments and potential system needs. It is our understanding CPB has proactively taken steps to highlight these factors in the applications process.

3. Your Mileage *Will* Vary

Beyond the generally positive conclusions above on the 1% IBOC mobile coverage and minimal impact to existing analog service the impact of elevated 10% power levels is subject to huge variability in consequences. One station may have a projected potential dramatic decline in analog coverage if all nearby stations began transmitting in HD, while another may have virtually no adverse impact. One station may experience a huge gain in mobile HD coverage, and another almost none. These factors are the inevitable result of overlaying a new, channel incompatible service on a fundamentally uncorrelated series of local signal environments. As a result we have resisted the traditional analysis of findings summarized by calculating averages, except in the limited instances where there are generally minor variations in results.

4. Indoor and Portable HD Radio Coverage Is Significantly Compromised

Indoor coverage has been reported to be seriously underperforming and this study documents that indoor HD coverage typically reaches less than half, roughly 40% of the analog indoor signal. Additionally, it is expected that the soon to arrive portable receivers will, due to the lower gain of their receiving antennas, experience similar poor performance relative to analog reception. Absent significant improvements in receiver designs, or increased IBOC power levels indoor and portable performance will continue to be significantly compromised compared to analog coverage. For indoor reception our options may be even more limited than the existing television broadcasters' efforts to promote "smart antennas" based on the lower frequencies and larger antennas required at FM frequencies. Resurgence in the use of outdoor antennas could be promoted but appears an unlikely candidate to significantly affect user patterns. Recent studies by audience research experts are documenting significant declines in the listening to radio at home. This factor should be carefully considered in determining what optimization steps are most appropriate in the future.

5. Potential Mobile IBOC Coverage At 10% Exceeds Existing Analog Coverage

This factor has to be considered carefully, as the potential to achieve a greater than pre-IBOC analog coverage area logically requires a complete transition to elevated HD Radio – and full conversion to digital receivers, something that will not be achieved in any foreseeable timeframe absent regulatory or legislative mandates.

Nonetheless, all but seven of the 49 large market stations studied would have a theoretical mobile reach greater than their pre-IBOC analog coverage if all stations were operating at 10% IBOC power levels. Here again the axiom "your mileage will vary" must be invoked. Although some stations would experience a slight coverage net loss (the worst casing being a 20% net loss), one station experiences a nearly 800% increase in population coverage and the average percentage change is a 62% population gain. Overall raw population coverage among the fifty larger market stations improves from approximately 98.5 million reached by pre-IBOC signals to approximately 115 million that would receive 10% IBOC mobile service—a 17% increase.

As one might expect the results are similar for the selected smaller market "rim shot" stations with three stations showing a net loss of coverage, one with a projected 35% loss, but among the others, eight show over 100% coverage gain and one reaches a stunning 974% population increase. The average is almost exactly double the analog pre-IBOC analog signal reach.

6. Analog Impact of En Masse 10% Power Elevation Could Be Severe

Almost half of the larger market stations would experience a greater than 20% loss of analog population coverage with 8 stations experiencing a greater than 50% reduction in analog coverage. Again, it must be cautioned that these numbers are based on ALL nearby stations operating at 10% IBOC power, a highly unlikely scenario. However, owing to the random case-by-case effect of effect of IBOC interference, interference to could be serious to an individual analog service from only one neighboring interferer. Assuming listener sensitive support was to experience commensurate drops, the quality of local programming services would be adversely affected, and in some stations station viability could be at risk.

7. No Convenient Basis Is Evident for a 10% Regulatory Authorization

Due to the variables in the impact on adjacent analog channels, the FCC would likely have to adopt a new approach to limiting any power increases based on corroborated prediction methods such as those explored in of this study. To avoid a seemingly random effect with a majority of stations reasonably clear of deleterious impact on their spectrum neighbors, while others experience impairments varying from slight to severe, methodology must be developed to predict the potential for interference due to elevated IBOC transmission power and apply it as a regulatory control on such operation. This prediction methodology could also be applied to other techniques that limit such IBOC interference, such as asymmetrical sideband levels, separate directional antenna systems for the digital transmission, and single frequency networks that direct digital signal fill-in away from potentially-affected neighbors.

8. New Optimization Considerations Merit Prompt Investigation

Tools for analysis of the effects of various unequal power levels have been developed in this study, which along with recent manufacturing flexibility in IBOC exciters could achieve and document the effective increase in coverage, as well as the analog interference mitigation an unequal sideband elevation approach might afford. Other approaches could be developed based on the unique challenges presented by IBOC introduction and efforts by the broadcast industry, service funders and regulators should be made to stimulate the advancement of new strategies.

9. Safeguarding Vulnerable Stations By Supporting Regulatory Advocacy

Consistent with its mission and any limitations on advocacy, CPB should help federal regulators in safeguarding against adverse audience impact, by supporting development of interference protection factors related to elevated IBOC sideband power. As discussed below, this could include funding technology developments that provide increased IBOC DAB coverage with the least impact on analog FM service.

Suggestions for further study in order to maximize the digital transition:

1. Independent Field Demonstration of SFN Digital Booster Viability

This may be one of the most promising and therefore urgent strategies for prompt investigation. As discussed below, advances in on-channel OFDM based boosters make it appear quite possible to adopt more of a cellular approach to digital coverage optimization which can dramatically minimize the adverse analog interference consequences encountered by unqualified sideband power increases.

Analog signal boosters or on-frequency repeaters have been deployed by broadcasters for years, with varying results. While the fill-in of signal by boosters is simple enough, in many cases the propagation time delay between the primary station and the booster at listener locations has caused serious multipath distortion. This effect is hard to avoid since stereo FM permits time differentials of only a few microseconds, or a kilometer or so, when the two signal levels are similar. Only boosters that have significant terrain shielding between the primary and boosted signals are likely to succeed, but enough terrain shielding to block multipath is rare.

IBOC DAB enjoys a much larger time differential between two signals of similar level, as much as 75 microseconds or 22 kilometers (14 miles) before inter-symbol interference occurs, causing a rise in bit-error rate. At these distances, the signal from the booster or is usually weakened sufficiently so that it does not interact with the primary station's signal.

Knowing the above characteristics of analog and digital boosters, it is apparent that a digital-only booster could fill in a shortfall in IBOC coverage, relative to analog service, without aggravating analog FM multipath. However, there are some engineering hurdles to accomplish a digital-only (or hybrid) booster. For example, the cost of a full digital generation and amplification system currently costs tens of thousands of dollars. In addition, digital data framing and encoding at both transmitters much be precisely synchronized. Finally, the data stream carrying audio and control signals must be relayed to the booster, which is likely to be located a large distance from the studio. These requirements make the current cost of a booster prohibitively high when limited numbers of listeners are served. A moderately low-cost booster system that meets the strict signal integrity and synchronization standards of IBOC DAB must be researched and developed.

Another hurdle in the design of an all-digital booster is the potential for interference to the station's analog FM signal in the vicinity of the booster. As one nears the booster, the IBOC digital signal will increase and possibly exceed the analog FM signal by many times. The behavior of analog FM receivers in these conditions, or the listener's tolerance for such impairment is not yet known. Tests of consumer receivers at highly elevated levels need to be performed and a computer prediction model needs to be developed to predict where serious degradation to analog reception may occur.

Software tools are needed to support the design of boosters, by recognizing the need based on geographic and demographic factors. Procedures and tools for the optimal placement of a booster, based on potential population served and avoidance of interference to the primary station, are needed. These tools should aid the use of a directional antenna for the booster to contain the digital signal within the station's authorized service area and to avoid increased interference to neighboring stations. This suggests the need to develop allocation policies to govern the deployment of boosters. Other pertinent studies include:

- The effectiveness of directional antennas to protect neighboring adjacent-channel stations from interference (which are effectively cochannel to prospective boosters)
- Determination of the best pathloss model to predict coverage of low-HAAT (less than 60 meter) boosters (most traditional point-to-point models are not suitable for distances of several kilometers; a suitable model would be an area-mode prediction)
- Effectiveness of boosters to fill in areas predicted to receive IBOC DAB interference, as compared to areas with weak primary station signal but low predicted interference (this may require field testing with a prototype booster)

The early work of CPB and NPR at KCSN's Beverly Hills booster site needs to be a priority for expansion, demonstration, and documentation. Prototype boosters should be built and deployed to verify the system design principles. This testing should include verification of multiple overlapping boosters as a true single-frequency network. (Some of this work cannot succeed without the assistance of iBiquity Digital Corp., which privately holds key elements of the IBOC signal generation technology.)

2. <u>Asymmetrical OFDM Sideband Power Elevation</u>

Because of the highly variable impact on analog coverage, as well as our field experiences with surprisingly good single sideband performance, unequal sideband power strategy could dramatically reduce the potentially serious negative analog impact of elevated sideband power, while also providing important coverage improvement at specific stations. Laboratory modeling of the expected results with analog and digital receivers should be followed with field trials to demonstrate the potential viability of this approach.

Areas of suggested study include:

- Measurement of interference to consumer receivers at highly elevated IBOC levels including subjective impact (listener testing) with
  - both fixed and mobile (fading) interference to first- and second-adjacent channel stations
  - various ratios of asymmetrical sideband transmission power
  - host compatibility with asymmetrical and elevated sideband power
- Theoretical and measured receive performance of asymmetrical transmission power, ranging from a pair of IBOC DAB sidebands at equal level to a single set of sidebands (necessary to develop a coverage prediction model at a given asymmetry ratio)
- Development of a technical approach, if feasible, for elevating one IBOC sideband in order to limit interference to a neighboring station on the alternate channel
- Development of practical regulatory policies to recommend to the FCC on behalf of public radio

3. <u>All Digital Service Planning Factors</u>

Learning from the experiences of the digital television transition underway now, the benefits of the eventual complete migration to digital radio transmission should be evaluated in the near future. Since it is the uncorrelated overlay of the 400 kHz IBOC signals on existing 200 kHz analog channels that results in such variable coverage and interference considerations, fundamental reassessments, including a possible band repacking, should be investigated to determine whether substantially greater spectrum efficiency and utilization can be achieved as we move towards an inevitably all digital future.

4. <u>SCA Compatibility Should Be Studied At 10% Elevated and Unequal Levels</u>

Public radio's longstanding support for radio reading services resulted in studies that assured minimal, if any, impact would befall analog sub-carrier (SCA) services from the introduction of HD Radio at 1%. Subsequently, LPFM developments were specifically conditioned on the protection of vulnerable SCA signals. This sensitivity should be extended by examining the potential impact on reading services from elevated IBOC levels, including the unequal power level strategy recommended above.

5. <u>Optimization Research</u>

As has been the case in the DTV transition, significant new technologies have been purpose-developed to overcome hurdles to a successful consumer adoption. This study highlights issues that may be ripe for concerted R&D proposals from interested stakeholders.

For the hundreds of public radio stations that have collectively invested many tens of millions of dollars in establishing digital radio operations in their communities, the excitement and benefits are now beginning in earnest as audiences continue to respond to the pioneering work of dedicated stations and staff. It is our hope that the information in this study will help maximize the emerging value of these new digital public services, while also helping document and safeguard the analog services that drive our industry.

Acknowledgements

NPR expresses our gratitude to the staff of CPB's Digital Media Technologies unit – especially Don Lockett, Senior Director of the unit, Brian Gibbons and Doug Vernier, who individually invested untold hours actively engaged in the progress and rigor of this study from inception to completion.

This study could not have happened with the extraordinary insights and dedication of NPR's Senior Technologist John Kean, the project manager on this effort. Kyle Evans, Jan Andrews, Ellyn Sheffield, Mike Starling, Dianne Brace, Daniel Schwab, and Barbara Freeman also contributed extensively throughout the study.

NPR Labs additionally thanks the staff at ITS in Boulder for customization of the CSPT planning tool for automating the execution of the mapping and population counts. Former NPR staffer Matthew Burrough also contributed to this project. Special thanks also goes to the staff of NPR's Audience Insight and Member Services groups for invaluable work on the signal sensitivity studies, especially Lori Kaplan, Barbara Appleby, Matt Gallivan, and Ben Robins.